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QUATERNARY TIME DIVISIBLE IN THREE PERIODS, THE LAFAYETTE, GLACIAL, AND RECENT.[1]

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According to definitions in text-books by Dana, Archibald Geikie and Etheridge, the Quaternary era began with the change from the mild Pliocene climate to that of the Glacial period, with its accumulation of the vast sheets of land ice in high latitudes, and has continued to the present time. We are living in the Quaternary era, as thus defined, and it must extend far into the future to be at all proportionate in length with the previous co-ordinate divisions of geologic time. Le Conte and Prestwich, however, consider the Quaternary division of time as completed at the dawn of civilization, with traditional and written history; and they assign recent geologic changes to a new era, named by Le Conte the Psychozoic, which is separated from the preceding principally on account of the supremacy of man. The former view seems preferable, because man is known to have been contemporaneous with the Ice age.

Quaternary time, therefore, is here assumed to include (1) the period of changed conditions causing the accumulation of

[1]Presented before Section E of the American Association for the Advancement of Science at the Brooklyn meeting, August 20, 1894; also partly contained in a paper read before the Geological Society of America, August 16, 1893, as published in its Bulletin, Vol. V, pp. 87–100, January, 1894.

the ice-sheets; (2) the Glacial period, when the glacial and modified drift were formed; and (3) the Postglacial, Recent, or Present period, extending from the departure of the ice-sheet until now. The first and second of these periods, which were comparatively long, constitute the Pleistocene division, while the third and very brief period is the Present or Psychozoic division, of the Quaternary era.

The Lafayette Period.

The broad lower part of the Mississippi Valley, from the southern boundary of the glacial drift to Louisiana, contains a very extensive unfossiliferous deposit of sand and gravel, designated formerly from its prevailing ferruginous color as the Orange sand, later called by McGee the Appomattox formation in its development on the costal plain of the Atlantic and Gulf States, but recently named the Lafayette formation, from Lafayette County in northern Mississippi, where it was earliest discriminated by Professor E. W. Hilgard in 1855 and 1856. This formation was spread across the valley plain 50 to 150 miles or more in width along an extent of 600 miles from the mouths of the Missouri and Ohio Rivers to the Gulf of Mexico, during the closing stage of the Tertiary era and the beginning of the Quaternary, to each of which it has been assigned. McGee,[2] Chamberlin[3] and Salisbury,[4] hold that it is probably referable to the Pliocene period; while Spencer,[5] Hilgard,[6] E. A. Smith[7] and others, as it seems to me preferably, have considered it as the earliest of our Pleistocene formations. Its northern continuation beneath the glacial drift is recognized by Salisbury[8] in western Illinois to a distance of a hun-

[2]Am. Journ. of Science, III, Vol. xxxv, February, April, May and June, 1888; Vol. xl, July, 1890. U. S. Geol. Survey, Twelfth An. Rep., for 1890–91, pp. 347–521, with 10 plates, and 45 figures in the text.

[3]Bulletin Geol. Soc. of America, Vol. i, 1890, pp. 469–480. Am. Jour. Sci., III, Vol. xli, May, 1891.

[4]Article last cited. Geol. Survey of Arkansas, An. Rep. for 1889 (published 1891). Vol. ii, "The Geology of Crowley's Ridge," pp. 224–248.

[5]Geol. Survey of Georgia, First An. Rept., for 1890–91, p. 62.

[6]Am. Jour. Sci, II, Vol. xlii, May, 1866; Vol. xlvii, Jan., 1869; Vol. xlviii, Nov. 1869; III, Vol. ii, Dec., 1871; Vol. xliii, May, 1892. Am. Geologist, Vol. viii, Aug., 1891, pp. 129–131.

[7]Am. Jour. Sci., III, Vol. xlvii, April, 1894.

[8]Bulletin Geol. Society of America, Vol. iii, 1892, pp. 183–186.

dred miles northward from the Missouri River and boundary of the drift, and gravels believed by him to be probably of the same formation occur in the Wisconsin and Minnesota driftless area, while northeastward he has observed the Lafayette gravels in the Ohio Valley in southern Indiana about 150 miles from the Mississippi. McGee states that the Lafayette beds attain their maximum thickness, which is 200 feet or more, in the region about the mouth of the Mississippi, and that they vary thence to a thin veneer, the thickness being proportional directly with the volume of neighboring rivers and inversely with the extension inland.

Previous to the maximum advance of the ice-sheet, the Mississippi River and all its large tributaries eroded deep and broad valleys through the Lafayette formation and underlying strata, cutting at New Orleans to a depth at least 760 feet below the present sea level. Along the central valley, from Cairo to the Gulf, this erosion averages probably 200 feet in depth upon a belt 500 miles long, with a width of 50 to 100 miles, excepting isolated plateau remnants of the Lafayette and older beds, of which the largest are Crowley's and Bloomfield ridges, in Arkansas and Missouri. The land during the valley erosion was certainly 760 feet higher than now, but this I think to be only a small fraction of its uplift. From the transportation of northern Archæan pebbles and cobbles of crystalline rocks to the Lafayette beds of the lower Mississippi and of Petite Anse Island, on the Gulf shore, in the direct line of the axis of the Mississippi Valley, Hilgard believes that during the deposition of these beds the valley had a greater descent and stronger currents of its river floods. He suggests that the increased altitude of the interior of the continent needed to give these formerly more powerful currents may have been 4000 to 5000 feet, being sufficient, probably, to bring the cold climate and ice accumulation of the Glacial period.

Marine submergence of the low coastal and Mississippi Valley areas occupied by the Lafayette formation is supposed by McGee and Spencer to have been requisite for the deposition of its sand and gravel beds, but they see that immediately

afterward the land was much higher than now, to permit the extensive and deep erosion of that time. A simpler view of the epeirogenic movements, closing the Tertiary era and inaugurating the Quaternary, seems to me to be found in ascribing these beds to deposition on land areas by flooded rivers descending from the Appalachian mountain region and from the Mississippi basin, spreading gravel, sand and loam over the coastal plain and along the great valley during the early part of a time of continental elevation. The land had lain during the long Tertiary periods at lower altitudes, and its surface was largely enveloped by residual clays and by alluvial sand and gravel. With the elevation of the continent, increased rainfall and snowfall and resulting river floods swept away these superficial materials from the higher lands and spread them on the coastal plain and along the Mississippi Valley, where the streams expanded over broad areas with shallow and slackened currents. As the elevation increased, however, the rivers would attain steeper slopes and finally erode much of the deposits which they had previously made. During the culmination of the uplift, which the writer believes to have been the chief cause of the Ice age, Chesapeake and Delaware Bays were excavated and erosion was in progress at a far more rapid rate than with the present low altitude of this region.

The Lafayette formation seems to me more closely related to the Glacial period and the conditions producing the ice-sheets than to the preceding very long Tertiary era, and for the same reasons which have been well stated by Hilgard and Spencer, namely, their dependence alike on the epeirogenic elevation.[9] With the Ice age we should unite this probably

[9]That epeirogenic movements of land elevation caused the accumulation of the Pleistocene ice-sheets, and conversely, that the end of the Glacial period was due to land depression, I have shown in an appendix of Wright's "Ice Age in North America," 1889, pp. 573–595; the Am. Geologist, Vol. vi, pp. 327–339, Dec., 1890; and the Am. Journal of Science, III, Vol. xli, pp. 33–52, Jan., 1891; and same, Vol. xlvi, pp. 114–121, Aug., 1893. This view, which may be called the epeirogenic theory of the causes of the Ice age, has been gradually thought out in America by Dana, LeConte, Hilgard, Wright and others, and in Scotland by Jamieson. Its earliest announcement was in 1855, by Dana in his Presidential Address before this Association (Proc. A. A. A. S., Vol. ix, for 1855, pp. 28, 29; Am. Jour. Sci., II, Vol. xxii, pp. 328, 329, Nov., 1856).

much longer preglacial time of gradual uplift of the continent, and the Postglacial or Recent period in which we live, to form together the three successive parts of the Quaternary era. How long the early part comprising the epeirogenic uplift, represented by the deposition and erosion of the Lafayette formation, may have been, we can only vaguely or perhaps approximately estimate. During the beginning of the uplift its effect would be probably to increase the transportation and deposition of gravel and sand by the rivers many times beyond their present action. The rate of average land erosion now prevailing throughout the drainage area of the Mississippi is supposed by McGee to be competent to supply in about 120,000 years a volume of river gravel, sand, and silt equal to the original Lafayette formation in the Mississippi Valley. With the greater altitude and increasing slopes of the land during the deposition of the Lafayette beds it may have required a third or a sixth of the time here mentioned, that is, some 40,000 or 20,000 years. As the elevation continued, however, rapid fluvial erosion of these deposits and of the underlying strata ensued, which was extended over so long and broad an area of the lower Mississippi Valley, and to such depth, that, even with the high continental elevation of 2000 to 3000 feet, known from submerged valleys off both the Atlantic and Pacific coasts, it must have required a long epoch. Perhaps it may be reasonably estimated twice as long as the time of the deposition, or somewhere between 40,000 and 80,000 years. The Lafayette period thus comprised two parts or epochs, the first characterized by deposition of the formation, the second by its extensive erosion and the culmination of the continental uplift.

The Glacial Period.

Comparison of the work of the glaciers and ice-sheets of the present time with those of Pleistocene time seems to me best accordant with a reference of all our glacial drift to a single continuous period of glaciation, which, though occupying probably 20,000 years or more, was yet brief as compared with the duration of most other recognized geologic periods or

epochs. The outflow of the upper part of the Pleistocene ice-sheets probably exceeded the currents of narrow alpine glaciers, but was less than the advance of broad and deep polar glaciers which end in the sea. For the journey of Pleistocene boulders 1000 miles in the ice-sheet, somewhat less than 3000 years would be required if the average of the glacial currents was five feet per day. The amount of the glacial erosion and of the drift, when compared with the erosion by the Muir glacier in Alaska, imply a short rather than a long duration of the Ice age. This conclusion is further affirmed by the continuance of the same species of the marine molluscan faunas from the beginning of the Glacial period to its end and to the present day.

The duration of the Ice age, if there was only one epoch of glaciation, with moderate temporary retreats and readvances of the ice-borders sufficient to allow stratified beds with the remains of animals and plants to be intercalated between accumulations of till, may have comprised only a few tens of thousands of years. On this point Prestwich has well written as follows: "For the reasons before given, I think it possible that the Glacial epoch—that is to say, the epoch of extreme cold—may not have lasted longer than from 15,000 to 25,000 years, and I would for the same reasons limit the time of . . . . the melting away of the ice-sheet to from 8000 to 10,000 years or less."[10]

Very gentle currents of broad river floods in the Missouri and Mississippi Valleys deposited the North American loess, attending the maximum extension of the ice-sheet and accompanying its departure up to the time of formation of the great marginal moraines. The loess thus testifies that previous to the farthest glacial advance the land sank to its present altitude, and probably somewhat lower on the area of the early drift, but not to the sea level. The vast weight of the continental glacier seems to have been the chief or only cause of this subsidence, as was first pointed out by Jamieson for the similar depression of the British Isles and Scandinavia at

[10]Quart. Jour. Geol. Soc., London, Vol. xliii, 1887, pp. 407, 408. Geology Vol. ii, 1888, p. 534.

the time of final melting of the European ice-sheet. The explanation of this continuance of the ice accumulation and advance after the depression of the land began and until the maxima, both of the land subsidence and ice extension, were attained, with a low altitude and even less descent of the lower Mississippi than now, has been well given by LeConte.[11] The subsidence was doubtless slow, even though probably many times faster than the preceding uplift. It may have occupied only 5000 years, being at a yearly rate of a half a foot to one foot; but possibly it was two or three times as long. While the slow sinking of the land was taking place, the accumulation of the ice by snowfall may have proceeded at a somewhat more rapid rate, so that the thickness of the ice-sheet and the altitude of its surface were increasing up to a maximum nearly coincident with that of the subsidence. Finally, however, the subsidence brought a warmer climate on the southern border of the ice, causing it to retreat, and giving to it in the region of the marginal moraines a mainly steeper frontal gradient and more vigorous currents than during its growth and culmination.

The time of general retreat of the ice-sheet in North America, with low altitude of the land and marine submergence of the coastal borders of northeastern New England, northward from Boston, and of the eastern provinces of Canada, with ingress of the sea along the valleys of the St. Lawrence and Ottawa Rivers and the basin of Lake Champlain, has been named by Dana the Champlain epoch. It was the final stage of the Glacial period, and was characterized by the rapid deposition of the glacial and modified drift, whose materials had been contained in the lower part of the ice-sheet.

The Postglacial, Recent, or Present Period.

Closely following the deposition of the modified drift as wide and deep flood-plains in the principal river valleys draining away from the departing ice, these beds were deeply eroded by the streams as soon as the ice-front had so far

[11] Bulletin Geol. Soc. of America, Vol. ii, 1891, pp. 329, 330. Elements of Geology, third edition, 1891, p. 589.

receded that the supplies of water and drift from its melting ceased. Much of the valley drift was soon removed by the river channelling, and its remnants, being left as terraces on the sides of the valleys, caused this first stage of the Postglacial period to be long ago named by Dana the Terrace epoch. In less vigorous action the streams have continued at the same work to the present day, so that this term may be extended also to comprise this whole period.

In various localities we are able to measure the present rate of erosion of gorges below waterfalls, and the length of the postglacial gorge divided by the rate of recession of the falls gives approximately the time since the Ice age. Such measurements of the gorge and falls of St. Anthony by Professor N. H. Winchell, show the length of the Postglacial or Recent period in Minnesota to have been about 8000 years; and from the surveys of Niagara Falls, Mr. G. K. Gilbert estimated it to have been 7000 years, more or less. From the rates of wave-cutting along the sides of Lake Michigan and the consequent accumulation of sand around the south end of the lake, Dr. E. Andrews believes that the land there became uncovered from its ice-sheet not more than 7,500 years ago. Professor G. Frederick Wright obtains a similar result from the rate of filling of kettle-holes among the gravel knolls and ridges called kames and eskers, and likewise from the erosion of valleys by streams tributary to Lake Erie; and Professor Ben. K. Emerson, from the rate of deposition of modified drift in the Connecticut Valley at Northampton, Mass., thinks that the time since the Glacial period cannot exceed 10,000 years. An equally small estimate is also indicated by the studies of Gilbert and Russell for the time since the last great rise of the Pleistocene lakes Bonneville and Lahontan, lying in Utah and Nevada, within the arid Great Basin of interior drainage, which are believed to have been contemporaneous with the great extension of ice-sheets upon the northern part of the North American continent.

Professor James Geikie maintains that the use of paleolithic implements had ceased, and that early man in Europe made neolithic (polished) implements, before the recession of the

ice-sheet from Scotland, Denmark and the Scandinavian peninsula; and Prestwich suggests that the dawn of civilization in Egypt, China and India may have been coeval with the glaciation of northwestern Europe. In Wales and Yorkshire the amount of denudation of limestone rocks on which drift boulders lie has been regarded by Mr. D. Mackintosh as proof that a period of not more than 6000 years has elapsed since the boulders were left in their positions. The vertical extent of this denudation, averaging about six inches, is nearly the same with that observed in the southwest part of the Province of Quebec by Sir William Logan and Dr. Robert Bell, where veins of quartz marked with glacial striæ stand out to various heights not exceeding one foot above the weathered surface of the enclosing limestone.

From this wide range of concurrent but independent testimonies, we may accept it as practically demonstrated that the ice-sheets disappeared only 6000 to 10,000 years ago. Within this period are to be comprised the successive stages of man's development of the arts, from the time when his best implements were made of polished stone through the ages of bronze, iron, and finally steel, to the present time when steel, steam and electricity seem to bring all nations into close alliance.

Estimated Duration of the Quaternary Era.

Arranged in chronologic order, we have derived for the three parts of the Quaternary era, as here defined, the following estimates of their duration: the Lafayette period or time of preglacial epeirogenic elevation, with the deposition and erosion of the Lafayette beds, some 60,000 to 120,000 years; the Glacial period, regarded as continuous, without interglacial epochs, attending the culmination of the uplift, but terminating after the subsidence of the glaciated region, 20,000 to 30,000 years; and the Postglacial or Recent period, extending to the present time, 6000 to 10,000 years. In total, the Quaternary era in North America, therefore, has comprised probably about 100,000 or 150,000 years, its latest third or fourth part being the Ice age and subsequent time. The Tertiary era appears by the changes of its molluscan faunas to have been

vastly longer, having comprised, perhaps, between two and four million years, of which the Pliocene period would be a sixth or eighth part, thus exceeding the whole of the ensuing era of great epeirogenic movements and resulting glaciation.

Divisions of Quaternary Time.

The following table of the several divisions, periods and epochs of Quaternary time, as reviewed in this paper, is arranged in the descending stratigraphic order of their geologic formations.

Psychozoic division	Recent period	Recent or Present epoch. Terrace epoch.
Pleistocene division	Glacial period	Champlain epoch. Glacial epoch.
	Lafayette period	Epoch of great elevation and erosion. Lafayette epoch.